FACTORS IMPACTING IDEA GENERATION EFFECTIVENESS: MAKERSPACE INVOLVEMENT, MECHANICAL ENGINEERING CURRICULUM EFFECTS, AND ENGINEERING DESIGN SELF EFFICACY

A Dissertation
Presented to
The Academic Faculty

by

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In Partial Fulfillment
of the Requirements for the Degree
Master of Science in the
G.W. Woodruff School of Mechanical Engineering

Georgia Institute of Technology
May 2020

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ACKNOWLEDGEMENTS

First, I want to thank Dr. Julie Linsey for her support and guidance throughout my graduate school career. I also want to thank my committee members, Dr. Amit Jariwala and Dr. Christopher Saldana, for their feedback and contribution toward this portion of the research. In addition, I want to thank my lab mates in iDREEM lab for their helpful advice during my time at Georgia Tech.

Next, I would like to thank my friends and family for being there for me and helping me become the person I am today. I want to especially thank my wife, parents, and siblings for being so supportive of me.

Lastly, I would like to acknowledge that this material is based upon work supported by the National Science Foundation under Grant Number DUE-1432107. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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LIST OF SYMBOLS AND ABBREVIATIONS

EDSE	Engineering Design Self-Efficacy
QQNV	Quantity, Quality, Novelty, and Variety

SUMMARY

In recent years, makerspaces have been growing in popularity. Research into makerspaces is increasing, but there is still limited evidence of their impacts. Students often design and prototyping and see others' designs in makerspaces. This likely increases idea generation skill and expands students' knowledge of existing designs. This work presents a longitudinal study of the impacts of makerspaces, specifically the correlation of involvement with idea generation ability and engineering design self-efficacy (EDSE). We collect freshman and senior data on makerspace involvement, idea generation abilities, and students' self-efficacy of engineering design skills to analyze how these factors change throughout an undergraduate mechanical engineering curriculum. Seniors are significantly more likely to be involved in makerspaces, report greater self-efficacy in design, and have greater idea generation effectiveness (quantity, novelty, and variety) than freshmen. Additionally, the seniors voluntarily involved in makerspaces showed higher idea generation quality, and the freshman with prior maker related experience from high school generated a larger quantity of solution concepts.

CHAPTER 1. INTRODUCTION

Makerspaces are community spaces for people from various backgrounds to develop their project ideas and prototypes; involved students and teachers report experiencing new ways of learning and teaching from makerspaces [1]. Research on makerspaces has become more prevalent [2] as more universities establish campus makerspaces with the hope of providing students with open access to hands-on experience in design, prototyping, and manufacturing. While the research is beginning to look at the benefits of makerspaces on innovation [3, 4] and the learning that occurs within them [1], there are still few data-driven empirical studies [2, 5] and the impact on idea generation skill has not been studied. Similarly, research on idea generation is extensive, but Genco et al. 2012 is one of the few studies observing the differences in idea generation ability between freshman and senior students [6]. The study presented in this paper aims to address these gaps by answering the following research questions.

1. **Does makerspace use correlate with idea generation?**
2. **What effect does makerspace use have on EDSE?**
3. **How does idea generation ability, makerspace involvement, and EDSE change from freshman to senior year?**
4. **Is there correlation between EDSE and idea generation?**

First, we explore the existing work that informed this study. Then, we discuss the experimental setting, instruments, and analytical procedure. The results are presented in accordance with the research questions, and then conclusions are drawn about the broader impacts of the findings from this study on the field of engineering education.

This study observes the idea generation abilities of undergraduate mechanical engineering students in a longitudinal study, focusing on the factors that may impact those abilities, such as makerspace involvement, self-efficacy, and growth effects from the engineering curriculum. Idea generation ability is determined by using Shah's metrics of idea generation effectiveness [7, 8] to score sketched participant solutions to a given design problem, but through a modified approach developed by Linsey et al. [9-11]. Engineering design self-efficacy (EDSE) [12] and makerspace involvement are gauged from responses to a survey instrument developed in prior work from Hilton et al. [13].

CHAPTER 2. BACKGROUND

The study presented in this paper observes the relationship between idea generation abilities and multiple potential impacting factors – namely, makerspace involvement, class standing in an undergraduate mechanical engineering curriculum, and engineering design self-efficacy (EDSE). The existing literature surrounding these topics is presented in the following subsections.

2.1 Idea generation

Idea generation has been extensively studied through different lenses, both in groups and individually. In order to draw meaningful conclusions about idea generation abilities under different conditions, it is first necessary to provide a method for measuring the value of ideas generated, or the effectiveness of one's idea generation process. Shah et al. identified the need to appropriately measure the effectiveness of engineering designs, and proposed four metrics – quantity, quality, novelty, and variety – to score sketched concept solutions to a given design problem [7, 8]. Next, we must understand the role of the design problems themselves used in idea generation experiments. Kumar and Mocko looked into this by observing similarities found in design problems used in a wide array of past experiments, and suggested the use of similar or benchmarked design problems across different experiments to enable meaningful comparisons across multiple studies [14]. Combining the concepts from both of these studies, research by Levy et al. [9] assessed the equivalency of four different design problems by comparing idea generation effectiveness results for each problem.

Lastly, it is important to understand how the experimental procedure of the idea generation activity can impact the creativity and effectiveness of participants. Liikanen et al. sought to understand this through the lens of time constraints and found that creativity suffers if participants are given either too little or too much time for the activity [15]. Multiple other studies similarly observe how idea generation effectiveness is impacted by various factors, such as the idea generation technique used [16], the mode of design representation used [11, 17, 18], or colocation/distribution of teams for group idea generation [19]. Another group of studies aimed to identify techniques or tools that could be used to improve idea generation effectiveness. For example, implementing design heuristics into the idea generation process to see their impact on students' exploration of the solution space [20], or using cognitive heuristics to improve design creativity [21, 22]. Despite the variety of existing research on idea generation, the impact of makerspace involvement on idea generation ability has not yet been observed. The study presented in this paper aims to address that research gap by comparing idea generation effectiveness of students with varying levels of makerspace involvement.

2.2 Makerspaces

Skovgaard Jensen describes makerspaces as community spaces for people from various backgrounds to develop their project ideas and prototypes; involved students and teachers report experiencing new ways of learning and teaching from makerspaces [1]. These makerspaces, as we know them now, began to emerge in the early 2000s [23] and experienced a large rise in popularity in the coming decades, with the number of makerspaces in operation worldwide increasing by 14 times in a ten year span [24]. Similarly, the amount of published research on makerspaces has been steadily increasing since 2013 [2]. Case studies have been conducted to survey various makerspaces in both the general community [25] and in academic settings [26, 27] to observe how they are operated, what types of equipment are commonly used, and how learning occurs in each space. These early research topics show the growing interest in understanding makerspaces, but do not provide information on the benefits of these spaces on students.

As the research field grew, more studies emerged searching for evidence of the impacts and benefits of makerspace involvement. A literature review by Vossoughi and Bevan presented anecdotal evidence of makerspace involvement encouraging STEM development and improving confidence in solving design problems [28]. One case study by Galaleldin reviewing makerspace best practices also included a student survey revealing self-reported makerspace involvement impacts on their skills in problem solving, design, and communication [29]. A few studies have also looked into how makerspaces can support innovation, with one finding that a group of makerspace users had a much higher rate of innovation than a demographically similar group of non-users [3]. A similar case study from Svensson observed makerspace innovations in a hospital setting and found that innovative individuals are more likely to join makerspaces, that involvement in the space most likely increases the chances of innovation, and that the value resulting innovations enabled by the makerspaces outweigh the investment required to establish and operate the space [4]. These two studies provide examples of how makerspaces can encourage innovation by allowing the opportunity for low risk development of projects and prototypes to solve encountered problems. However, there is lack of empirical evidence overall to support the suggestion of specific learning outcomes enhanced by makerspace involvement [2, 5]. Recent studies related to this research have revealed positive correlations between makerspace involvement and self-efficacy [30, 31], as well as academic performance [32]. This paper aims to supplement the findings from prior work by introducing potential relationships between makerspace involvement and design idea generation ability.

2.3 Engineering curriculum outcomes (Expertise effects on idea generation)

In addition to makerspace impacts on idea generation, the effects of expertise gained from the undergraduate curriculum must also be considered. Studies observing the effects of incorporating project-based learning into engineering design curricula suggest an improvement of involved student's retention, satisfaction, and learning [33]. This outcome is encouraging for the assumed benefits of makerspaces considering the close relationship between project-based learning and makerspace involvement. Existing research on undergraduate engineering curricula by Genco, Holtta-Otto, and Seepersad [6] investigated the innovation capabilities and creativity of freshman and senior engineering students, and found freshman showed more creativity based on a significant difference in originality of design concepts between the two groups and no significant differences in technical feasibility. However, senior students presented more detailed solution concepts, which included additional considerations from knowledge gained in the curriculum [6].

2.4 Self-efficacy

The final lens through which idea generation and makerspace involvement impacts are observed is self-efficacy. Self-efficacy, as defined by Bandura, is a measure of one's self-belief in their abilities [34]. In other words, it shows their level of self-confidence in being able to complete a given task. His studies suggest a relationship between self-efficacy and success [34], meaning individuals with high self-efficacy are more likely to accomplish the related task more effectively. This study focuses specifically on engineering design self-efficacy (EDSE), which is a group of self-reported metrics measured through the instrument developed by Carberry et al. [12] to gauge one's inclination toward design tasks. EDSE is divided into four categories, confidence, motivation, success, and anxiety. Together they provide insight into the students' self-perception of their design abilities. Since self-efficacy can be a potential predictor for success or effectiveness, this study observes the relationship between EDSE and idea generation effectiveness for any potentially significant correlations.

- [https://doi.org/10.1115/1.4041173] Are creativity and self-efficacy at odds? [35]

CHAPTER 3. METHOD

This paper focuses on the idea generation portion of a larger longitudinal study by Hilton et al. [13, 30]. Longitudinal data on makerspace involvement, idea generation effectiveness, engineering design self-efficacy (EDSE), were collected as students progressed through the engineering curriculum.

3.1 Experiment Setting

This study was conducted at a research-focused, ABET-accredited university in the Southeastern United States. Participants were recruited from undergraduate mechanical engineering design courses required during freshman and senior year.

Multiple makerspaces operate on the university's campus. The spaces vary in size, type of equipment, school of focus, physical location on campus, organizational structure, and length of operation. The campus makerspace housed in the mechanical engineering department is student-run, has been operating for over 10 years, and is open to all students. This space is the most referenced by participants who report being involved in makerspaces. The mechanical engineering curriculum involves projects which encourage makerspace use; however, it is possible for students to complete the curriculum without using any makerspaces.

3.2 Instruments

Initial data collection for idea generation used four problem statements: Device to Shell Peanuts, the Device to Aid in Shucking Corn, Device to Aid in Coconut Harvesting, and

Personal Alarm Clock. Much of the analysis focuses on the device to shell peanuts, which involves designing for a user who needs to shell a large volume of peanuts quickly, with little damage to the nuts, a small budget, and no access to electricity or complex manufacturing techniques. It has been used as a design problem from experiments before [14, 18, 36]. For brevity, the problem statements will hereafter be referred to as peanut, corn, coconut, and alarm respectively. See Appendix A for each design problem with an associated participant solution. Idea generation ability was determined by using Shah's metrics of idea generation effectiveness [7, 8] to score sketched participant solutions to the given design problem, but through a modified approach developed by Linsey et al. [9-11].

A survey instrument gathered self-reported data on makerspace involvement, engineering design self-efficacy, and demographic information. Makerspace involvement was divided into three categories according to prior work by Hilton et al.: no involvement – for students who reported never using any makerspace equipment, class-only involvement – for students who reported using makerspace equipment only for required course projects, and voluntary involvement – for students who reported using makerspace equipment for anything beyond class projects (i.e. personal, club/organization, or research related projects) [13, 30]. Prior work explored other categorizations based on the available survey data and found these to provide the most insight into the data [13].

The engineering design self-efficacy (EDSE) instrument developed by Carberry et al. [12] was used to collect self-reported data on students' confidence, motivation, expectation of success, and anxiety surrounding engineering design in general.

3.3 Data Collection Procedure

Participants enrolled in a freshman-level introduction to engineering graphics (CAD) course provided the first-year data. Senior collection occurred in the senior-level capstone design course (mostly mechanical engineering). These collection points provide snapshots of students' abilities at the start and finish of the undergraduate curriculum for between-subject comparisons. Participants from initial collection were tracked and invited to participate in the study again upon enrolling in the senior level capstone design course to allow for longitudinal samples for within-subject comparisons. Unfortunately, the sample size collected from longitudinal seniors was low due to lack of participation, so statistically significant within-subject comparisons were not possible.

During the experiment, participants worked individually. For the idea generation portion, participants were instructed to sketch and label as many design solutions as possible for forty-five minutes. Instructions for the activity specified that participants should sketch only one solution per page to make separate solutions easily distinguishable. Participants were given time warnings at 5 and 2 minutes remaining. Participants then received the survey instrument, either on paper or electronically. Upon completion, participants were compensated with cash for their time.

CHAPTER 4. RESULTS

4.1 Data Coding and Inter Rater Reliability

All 29 senior participants' data were rated by the author. A second rater, a graduate student in the same lab, was trained for interrater reliability, which involved both raters coding a practice-only data set of 7 participants, followed by discussing any disagreements or deviations from the coding guidelines. After training, the second rater coded a subset of 15 from the 29 senior participants, and the inter-rater agreement on average participant scores was evaluated using Pearson's correlations for each idea generation effectiveness. The resulting Pearson's correlations shown in Table 1 below suggest high inter rater agreement. Quality for each individual solution, rather than average participant score, were also evaluated for further inter-rater agreement. Detailed descriptions of the coding procedure [9-11] for each idea generation effectiveness metric are in Appendix B.

Table 1 - Inter-rater Reliability for Idea Generation Effectiveness Coding

Idea Gen Metric	Pearson's Correlation (r)	Agreement on Quality for Individual Solutions		
Quantity	0.9248	Pearson's Correlation	% Agreement	Cohen's Kappa
Quality	0.9809	0.796	0.841 (84%)	0.707
Novelty	0.8818			
Variety	0.8736			

4.2 Data Analysis

Idea generation effectiveness was compared with makerspace involvement, high school maker related activity, EDSE, and class standing. Two-sample t-tests, assuming unequal variances, were used for analysis when comparing metrics like idea generation effectiveness and EDSE between two groups, such as for freshman versus senior students. The significance (p) values reported are results from one-tailed hypothesis tests examining whether one sample's mean is greater than the other. ANOVA was used to analyze differences in metrics across three comparison groups, such as for the three levels of makerspace involvement. A chi-squared test was used to compare the distributions of makerspace involvement by class standing. Linear regression analysis was also conducted to observe correlations between idea generation effectiveness and EDSE.

4.3 What effect does makerspace use have on idea generation and EDSE?

Participants were divided into various makerspace involvement groups [30] based on survey responses, and the average idea generation effectiveness scores from each group were compared. The freshman survey also included questions on high school maker related activities, such as shop classes or robotics teams.

The following two figures present the idea generation results for freshman and senior students based on their university makerspace involvement level. Figure 1 shows a significant difference in idea generation variety among freshman. Surprisingly, students involved in makerspaces scored lower in variety for the corn problem ($t(30) = 1.722$, $p = 0.048$). Figure 2 shows a significantly higher idea generation quality for senior-level voluntary makerspaces users ($t(21)= -3.103$, $p<0.01$) compared to seniors with either class-only or no makerspace involvement.

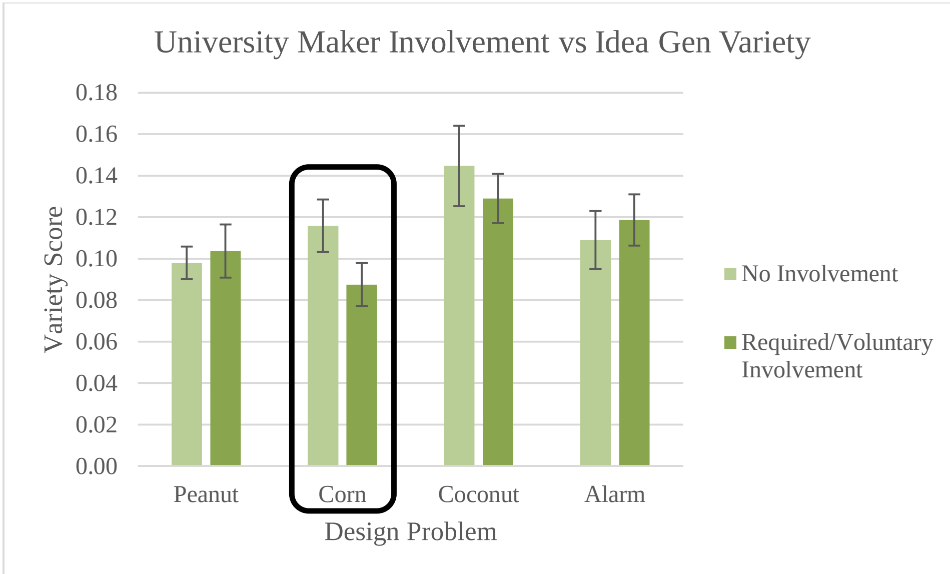

Figure 1 - Differences in Freshman Idea Generation Effectiveness by Makerspace Involvement Level

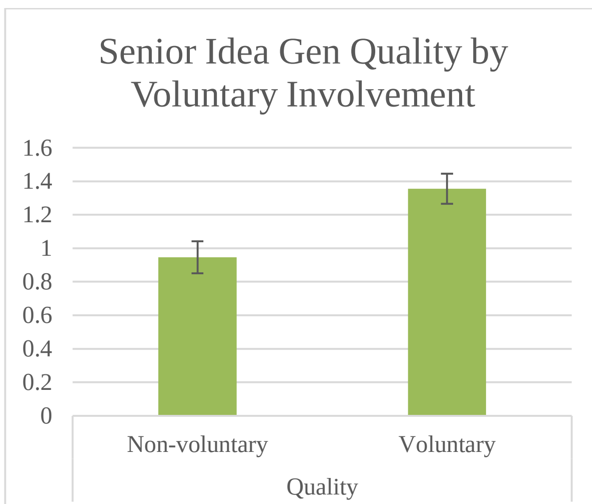

Figure 2 - Differences in Senior Idea Generation Effectiveness by Makerspace Involvement Level

The results presented in the next four figures show the freshman-level differences in idea generation effectiveness students based on prior maker related experience from high school. Figure 3 shows the proportions of freshman students in each problem group who had prior maker related experience from high school, and the subsequent Figure 4-Figure

6 show the idea generation effectiveness differences between these groups. Students with high school maker related experience exhibited higher idea generation quantity for the peanut problem (t(28) = -2.813, p<0.01), lower quality for the corn and alarm problems (Corn – t(30) = 1.656, p = 0.054; Alarm – t(29) = 1.495, p = 0.073), and lower variety for the coconut problem (t(29) = 1.6702, p = 0.052).

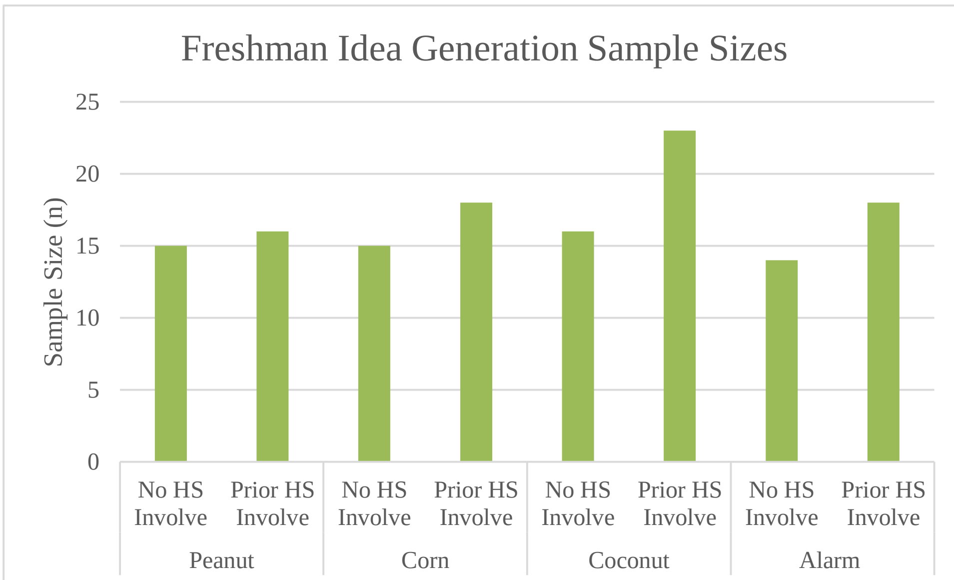

Figure 3: Freshman Idea Generation Sample Distribution based on High School Maker Related Activity

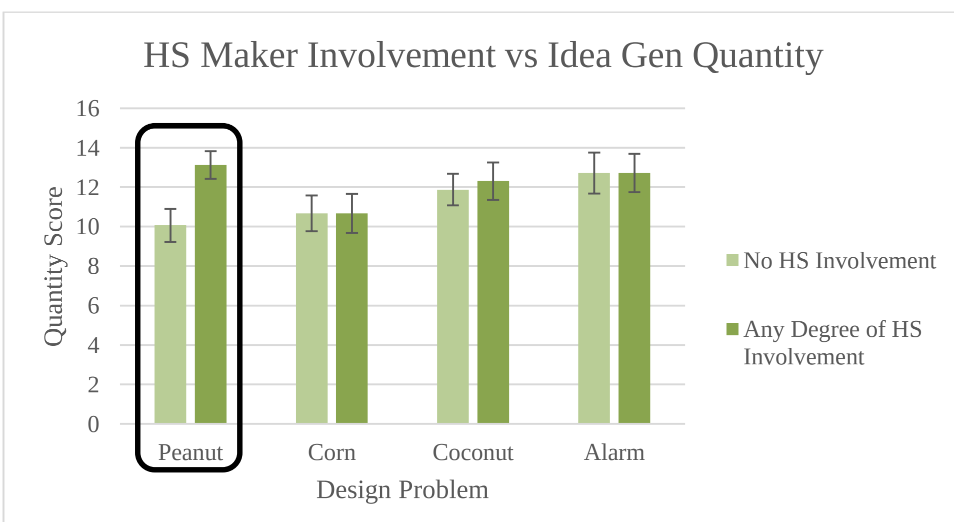

Figure 4: Impact of HS Maker Related Activity on Freshman Idea Generation Quantity

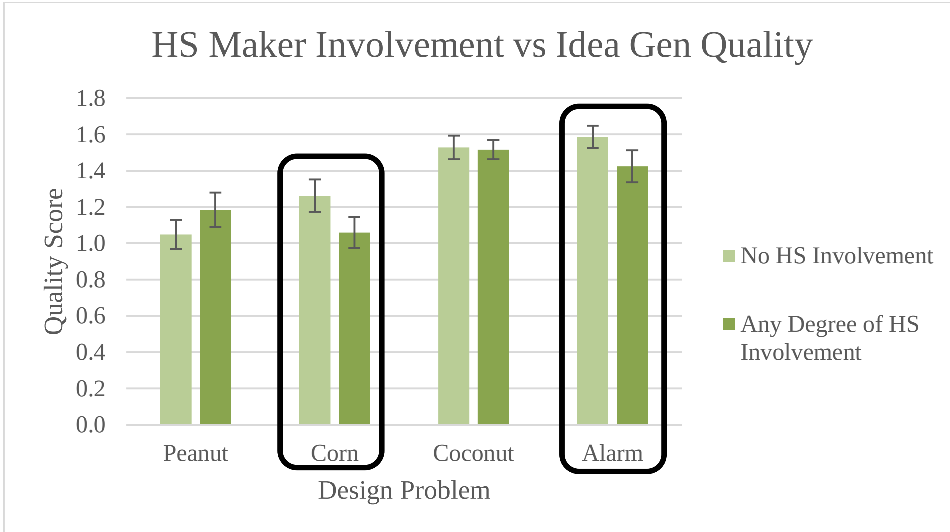

Figure 5: Impact of HS Maker Related Activity on Freshman Idea Generation Quality

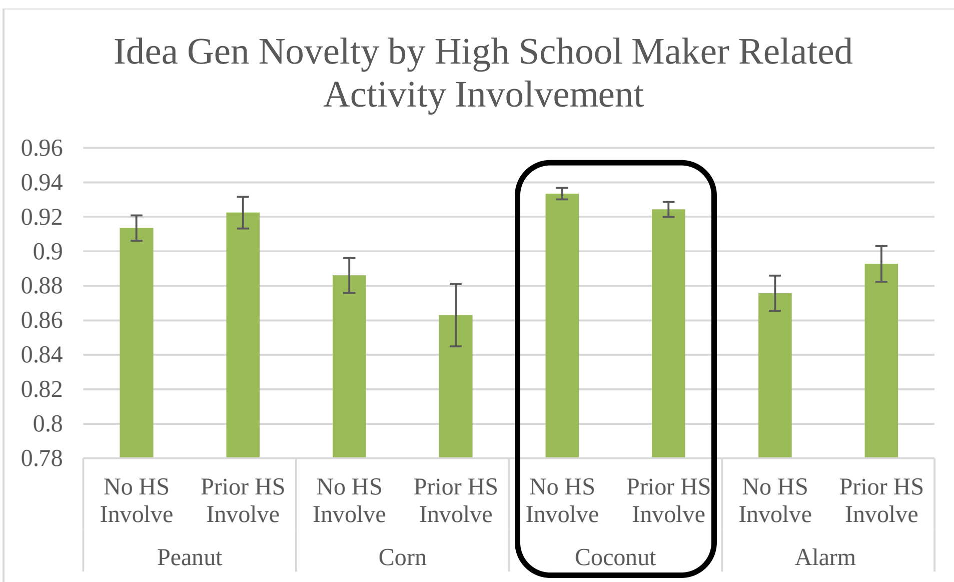

Figure 6: Impact of HS Maker Related Activity on Freshman Idea Generation Novelty

4.4 What effect does makerspace use have on EDSE?

EDSE of both freshmen and senior students were also compared based on makerspace involvement similar to previous work by Hilton et al.[13, 30]. ANOVA analysis was conducted for the entire freshman sample comparing EDSE with makerspace involvement (chart shown in Figure 7). A significant relationship was found between EDSE motivation and makerspace involvement ($F(2,132)=6.894$, $MSE = 417.87$, $p<0.01$, and $\eta 2 = 0.095$). Freshman with either voluntary or class-only involvement reported significantly higher motivation than those with no involvement according to the two sample t-test ($t(21) = -2.073$, $p = 0.025$). The bar chart in Figure 8 shows the comparison. These findings are consistent with prior work [13, 30]. Seniors did not show any significant differences, which could be attributed to low sample size.

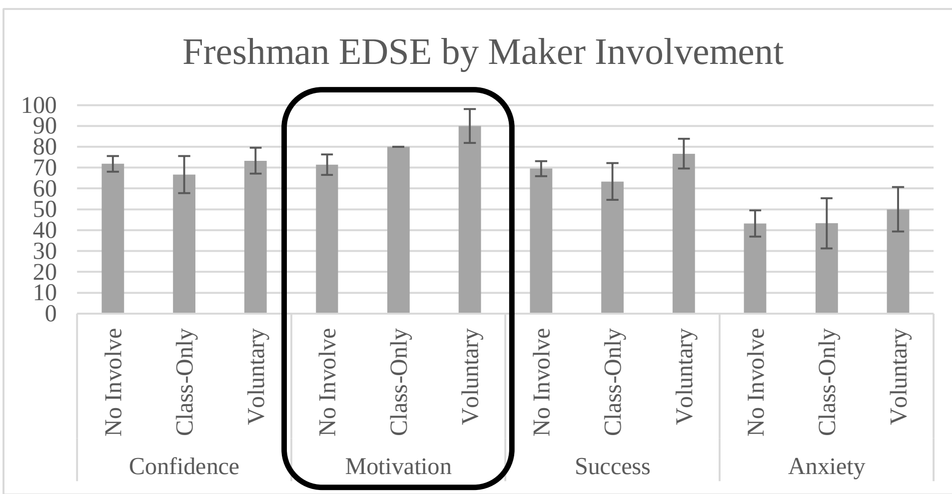

Figure 7: Comparison of Freshman EDSE by University Makerspace Involvement

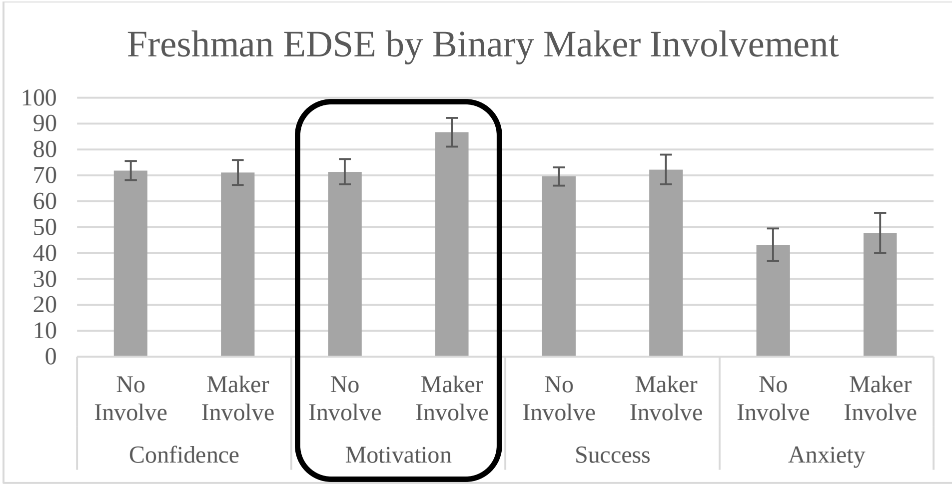

Figure 8: Comparison of Freshman EDSE by Binary Involvement

4.5 How does idea generation ability, makerspace involvement, and EDSE change from freshman to senior year?

Figure 10 shows the distributions of makerspace involvement by class standing. The chi-squared test of proportions revealed a significant difference in involvement between freshmen and seniors ($\chi 2$ (2, N = 60) = 20.4561, $p<0.01$), showing that seniors are more likely to be voluntarily involved and less likely to have no makerspace involvement than freshmen.

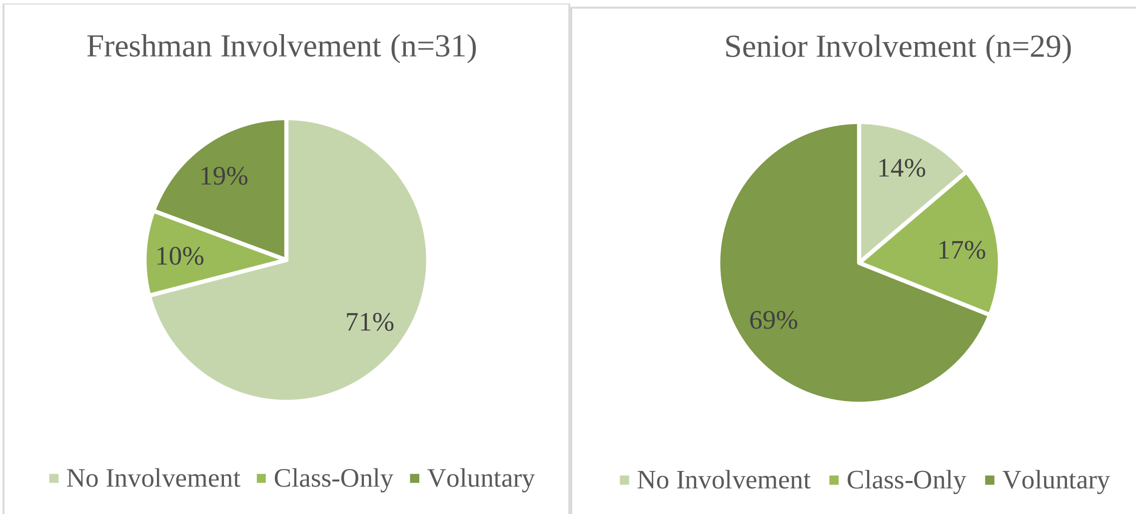

Figure 10: Distribution of Makerspace Involvement Levels between Freshmen and Seniors

The idea generation effectiveness comparisons by class standing are shown in figure 11 below, where seniors outperformed freshmen in three of the four effectiveness metrics (Quantity – $t(48) = -4.298$, $p<0.01$; Novelty – $t(49) = -2.115$, $p=0.02$; and Variety – $t(44) = -3.377$, $p<0.01$). Only idea generation quality had no significant difference by class standing, but with an increased sample size of # participants, this finding could also be significant.

Figure 11: Idea Generation Effectiveness Comparisons between Freshmen and Seniors

The class standing differences in EDSE are shown below in figure 12, where seniors again scored higher in three of the four EDSE categories (Confidence – t(58) = -2.28, p=0.013; Expectation of Success – t(55) = -3.119, p=0.014; and Anxiety – t(57) = 1.529, p=0.066), leaving only motivation at similar levels for both groups.

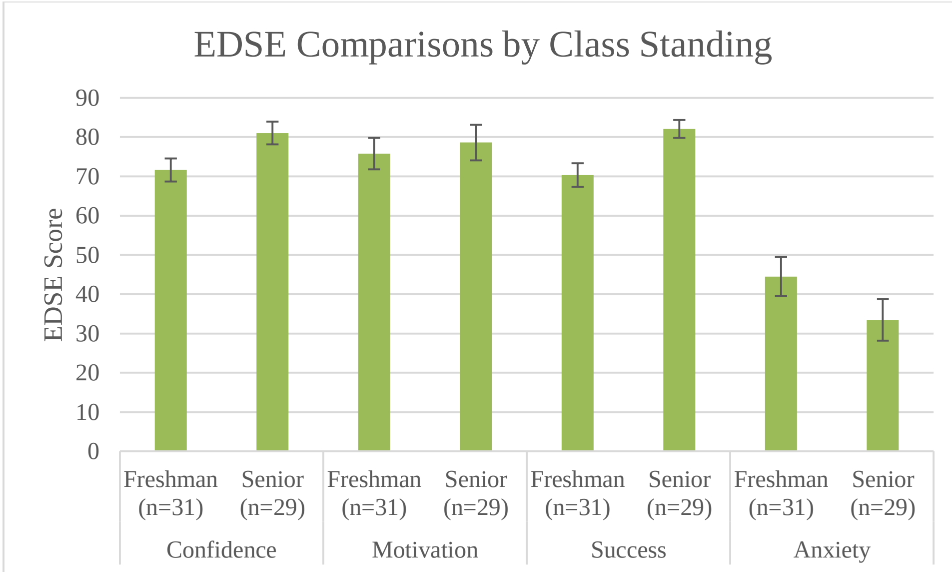

Figure 12: Comparison of EDSE between Freshmen and Seniors

4.6 Is there correlation between EDSE and idea generation?

Linear regression was performed between idea generation effectiveness metrics and EDSE scores, with idea generation effectiveness as the dependent variable. This provided a preliminary glimpse into the relationship between students' self-perception of their design abilities and their effectiveness in generating solutions to a given design problem. The results tables from these linear regression analyses can be found in Appendix C. With the sample sizes available, significant results are limited. However, a near-significant positive correlation was found between quantity and motivation in the freshman sample ($F(1,62) = 2.356$, $p = 0.130$, $R^2 = 0.037$), suggesting that highly motivated students may produce a larger quantity of ideas. The senior sample size for linear regression was less than half that of the freshmen, but the results indicate potentially significant correlations between quality and motivation ($F(1,27) = 2.994$, $p = 0.095$, $R^2 = 0.100$), as well as novelty and confidence

($F(1,27) = 3.8155$, $p = 0.061$, $R^2 = 0.037$). More data is needed in order to draw significant conclusions from the results.

Summary of results by associated research question

1. **Does makerspace use correlate with idea generation?**
    a. Voluntarily involved seniors scored higher in Quality
    b. Involved freshman scored lower in Variety
    c. Freshman with prior maker related activity in HS
        i. Scored Higher in quantity (peanut)
        ii. Scored Lower in variety (corn & alarm)
        iii. Scored Lower in novelty (coconut)
2. **What effect does makerspace use have on EDSE?**
    a. High EDSE motivation linked to more makerspace involvement (same as prior work)
3. **How does idea generation ability, makerspace involvement, and EDSE change from freshman to senior year?**
    a. Seniors achieve greater idea generation effectiveness than freshman (quantity, novelty, variety)
    b. Seniors exhibit greater EDSE than freshman (Confidence, Expectation of Success, Anxiety)
    c. Seniors compared to freshman are:
        i. much more likely to be voluntarily involved
        ii. much less likely to have no involvement at all
4. **Is there correlation between EDSE and idea generation?**
    a. Correlation between motivation and quantity (freshman)
    b. Correlation between motivation and quality (senior)
    c. Correlation between confidence and novelty (senior)

4.7 Discussion

The regression analyses from both the freshman and senior sample demonstrate at least a weak association between students' self-perception of the design abilities and their idea generation effectiveness. With further data and analysis, understanding an engineering student's degree of confidence and motivation regarding engineering design could help predict patterns in their idea generation effectiveness.

The results comparing idea generation effectiveness makerspace involvement showed that voluntarily involved seniors scored higher in idea generation quality, while involved freshmen scored lower in variety (corn). For freshman students, the high school maker related activities, such as robotics teams or shop classes, were linked to higher idea generation quantity (peanut), but lower idea generation quality (corn and alarm) and novelty (coconut). These findings suggest a relationship between makerspace involvement and idea generation ability, but further research is needed to gain a deeper understanding of this relationship.

Direct class standing comparisons showed stark differences between seniors and freshmen. Seniors have a significantly larger proportion of students voluntarily involved in makerspaces, significantly lower proportion of students with no makerspace involvement. This suggests that students are much more likely to be voluntarily involved in makerspaces by senior year. The differences in the idea generation abilities and EDSE suggest various improvements throughout the engineering curriculum. Seniors, in terms of their idea generation effectiveness and engineering design self-efficacy, score better than freshman in three of four categories for both metrics.

Looking at all of the results together, there is a clear division between freshman and senior students. Seniors are more likely to be involved in makerspaces, report higher EDSE scores than freshman in every category except motivation, and score higher in idea generation effectiveness in every category except quality. Makerspace involvement also plays a role in influencing idea generation ability according to the differences in various effectiveness categories based on involvement level. Additionally, some of the EDSE categories, specifically motivation and confidence, were identified as potential predictors for idea generation effectiveness metrics, like quantity, quality, and novelty. These correlational results lay the groundwork for future experiments to pursue causal evidence.

CHAPTER 5. CONCLUSION

The major findings from this study were the significant differences that emerged between seniors and freshmen, along with the correlations between EDSE and idea generation effectiveness. Discovering that EDSE could be a significant predictor for idea generation effectiveness suggested that the participants' confidence and motivation to conduct engineering design impact their ability to generate ideas to a given design problem. The improved idea generation effectiveness scores observed in seniors suggest that domain knowledge and design experience gained throughout the curriculum could also have an impact on their idea generation abilities. Additionally, the distribution of makerspace involvement levels for the freshman and senior samples showed significantly more involvement among seniors, and EDSE motivation was a significant predictor for increased makerspace involvement. Coupling all of these findings together with the fact that seniors also reported higher EDSE on average than freshman further supports the extensive interconnectivity between these factors.

Seniors from this study were better idea generators, reported better EDSE scores, and were more involved in makerspaces than their freshman counterparts. While there is no evidence of a direct causal relationship between these metrics and the effects of the undergraduate curriculum, the fact that the senior results are greater in all three categories cannot be ignored. Furthermore, the various correlations between EDSE, idea generation effectiveness, and makerspace involvement support that these factors may be symbiotically improving over time or as engineering design knowledge and experience grow throughout the undergraduate curriculum.

The broader impacts of this study could apply not only to engineering education, but perhaps industry as well. For engineering education, this study serves as a starting point for understanding and measuring the impacts of a mechanical engineering curriculum on design, and how students in the program develop from their first to their final design related course. It also adds to the argument that hands on prototyping and design experience gained in makerspaces can be linked to improvements in student design abilities or attitudes like idea generation effectiveness or EDSE. Together these outcomes suggest the benefits of incorporating required makerspace use into the curriculum if only for initial exposure to increase the likelihood of voluntary involvement over time. For industry, these findings could be extrapolated to suggest that both the level of experience and the self-reported EDSE factors like confidence and motivation can be viewed as predictors for idea generation effectiveness among designers. Also, similar to the academic outcomes, hands on prototyping experience through participation in makerspaces or similar activities could be beneficial for bolstering the existing capabilities of working engineers.

5.1 Future work

Future work involves conducting this type of longitudinal study again to increase sample size for observing direct within subject changes in idea generation, EDSE, and maker involvement. Also, expanding the idea generation portion of this study across multiple universities and disciplines would make the results more robust and generalizable. A deeper look into the makerspace involvement data is needed to conduct regression and ANOVA analysis to determine the extent of the impact that makerspace involvement has on idea generation effectiveness. Additionally, the makerspace survey data can be further analyzed to determine more detailed classifications of makerspace involvement, which may reveal richer relationships between involvement and idea generation effectiveness. Lastly, additional studies need to be conducted to gather evidence of causal relationships between these factors for which only correlational results were found.

APPENDIX A. IDEA GENERATION ACTIVITY INSTRUMENTS

Design Problems

Device to Shell Peanuts

Problem Description:

In places like Haiti and certain West African countries, peanuts are a significant crop. Most peanut farmers shell their peanuts by hand, an inefficient and labor-intensive process. The goal of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

Customer Needs:

- Must remove the shell with minimal damage to the peanuts.
- Electrical outlets are not available as a power source.
- A large quantity of peanuts must be quickly shelled.
- Low cost.
- Easy to manufacture.

Please sketch and note (with words) one design solution per page starting on the next page.

Device to Aid in Shucking Corn

Problem Description:

Corn is currently the most widely grown crop in the Americas with the United States producing 40% of the world's harvest. An ear of corn has a protective outer covering of leaves, known as the husk, and strands of corn silk threads run between the husk and the kernels. The removal of husk and silk to clean the corn is known as shucking corn. Design a device that quickly and cheaply shucks corn for mass production.

http://www.art-photograph-gallery.com/pictures-of-corn.html

Customer Needs:

- Must remove husk and silk from corn cob with minimal damage to kernels.
- A large quantity of corn must be shucked quickly.
- Must be safe for user
- Easy to manufacture
- Low cost.

Please sketch and note (with words) one design solution per page starting on the next page.

Device to Aid in Coconut Harvesting

Problem Description:

In certain places like the Philippines, Indonesia, and India, coconut harvesting is a major practice. The current process requires a skilled person to climb the tree and cut down the coconuts. The average height of a coconut tree is 35-40 feet and though there are grooves along the tree that make it easier to climb, the tree surface becomes very slippery during the rainy seasons. The current process may take as long as 12 hours for large farms that average 150 trees. The goal of this problem is to design a low-cost product to improve the coconut harvesting process so that it is safer and can be done more quickly.

Customer Needs:

- Must remove coconut with little damage to fruit and tree
- Must be safer to operate than current method.
- Must harvest coconuts quicker than current method
- Electrical outlets are not available as a power source.
- Low cost.

Please sketch and note (with words) one design solution per page starting on the next page.

Personal Alarm Clock

Problem Description:

Alarm clocks are widely used to help individuals wake from slumber. However, when used in shared spaces like dorm rooms, they will often disturb those around them. The goal of this problem is to design a low-cost alarm clock for individual use that will not disturb others. The clock should be portable for use in a variety of situations such as on the bus, in the library, or in a classroom.

Customer Needs:

- Must wake up individual with no disturbance to others.
- Must be portable and lightweight.
- Must be safe for user.
- Electrical outlets are not available as a constant power source.
- Low cost.

Please sketch and note (with words) one design solution per page starting on the next page.

Data Coding

Quantity

Quantity was coded based on the total number unique components included in all of a participant’s solutions. Unique components were usually both sketched and labeled by the participant, but in some cases it was either an unlabeled sketch or just a label. Inclusion of unlabeled sketch components was based on the discretion of the rater, but in general, they were only counted as unique components if the sketch was easily identifiable (ex. Gears, conveyor belts, etc.). Repeated use of a unique component did not count toward the quantity score. For example, if there were three different design solutions that included some form of hand crank, the quantity score would only be increased by 1 for the first hand crank, and the all following hand cranks are ignored.

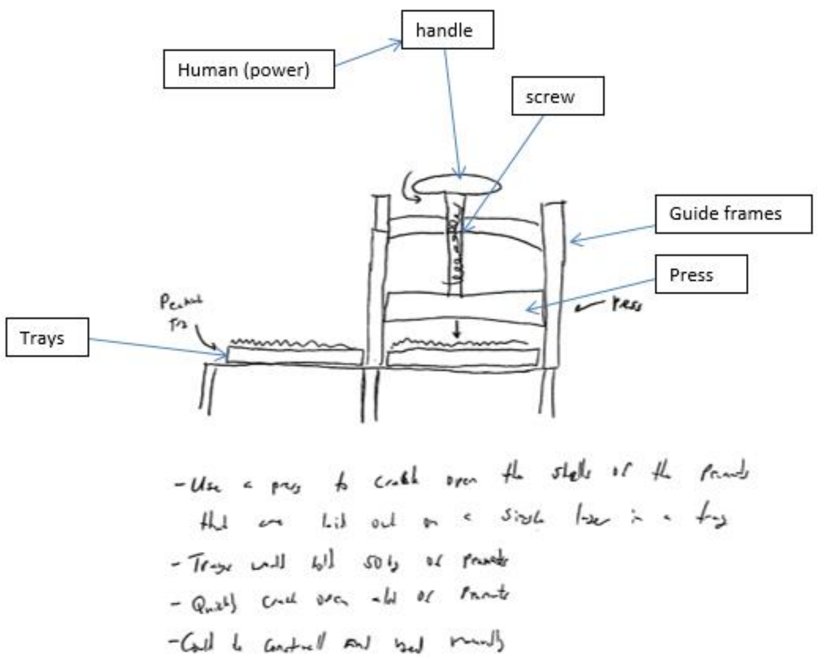

Figure 9: example solution with components labeled for quantity

Quality

Quality scores were coded based on technical feasibility of the designs, and how well the designs met the criteria listed in the problem statement. A minimum score of 0 was given to infeasible designs, a score of 1 was given for technically feasible designs that only met a few of the design criteria, and a maximum score of 2 was given for designs that were technically feasible and met most or all of the design criteria. Each of the participant’s design solutions were given individual quantity scores, and then an average quantity score was calculated for all of their solutions.

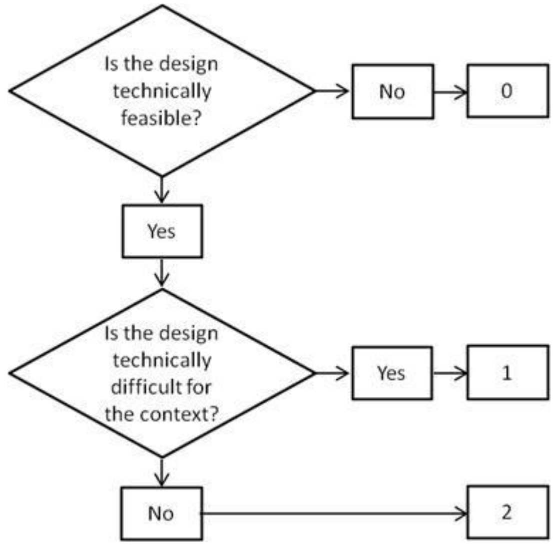

Figure 10: Flowchart for scoring quality of solutions

Novelty and Variety (Solution Bins)

Novelty and variety scores were both based on how the participant solutions compared to the solution bin list. The bin list contained all possible or previously seen types of solutions, and was used to categorize participant designs. Every solution is assigned to at least one bin. One design solution could fit into multiple bins, and multiple designs from a participant could fall into the same bin.

Novelty

The novelty score is based on the frequency of specific solution types compared to the total number of solutions. The more solutions in the overall set that fit into a specific bin category, the lower the novelty score of those solution types. Conversely, if very few solutions in the data set are within a specific bin category, the novelty score of that category would be high. For example, the novelty of solutions involving rollers is calculated by finding the total number of roller based solutions in the set, dividing that number by the total number of solutions of all types in the set, and subtracting that value from 1. Each student's novelty score was an average based on which bin categories their solutions fit into.

Variety

To calculate the variety score, the amount of bin categories filled by a participant's solutions was compared to the total number of bin categories; the more spread a participant's solutions had across the categories in the bin list, the higher their variety score.

APPENDIX B. MAKER SURVEY INSTRUMENT

Maker Survey - Capstone Fall 2019 - IDEA GEN

Start of Block: Maker Survey

*

- ○ First Name: ____
- ○ Last Name: ____
- ○ Email: ____
- ○ GTID# (90XXXXXXX) ____

1. What is your current major?
Select one

- ○ Aerospace Engineering
- ○ Biomedical Engineering
- ○ Chemical Engineering
- ○ Computer Engineering
- ○ Electrical Engineering
- ○ Industrial Engineering
- ○ Material Science Engineering
- ○ Mechanical Engineering
- ○ Nuclear Engineering
- ○ Other (Please Specify) ____

2. Which of the following courses are you currently taking?

- ☐ ME1770
- ☐ ME 2110
- ☐ ME 4182 (Capstone)
- ☐ BME 2310
- ☐ BME Capstone

Q54 What professor did you have for ME 1770?

- ○ Denis Dorozhkin
- ○ Katherine Fu
- ○ Julie Linsey
- ○ Raghuram Pucha
- ○ Other (please specify): ____
- ○ I did not take ME 1770 at Georgia Tech
- ○ I do not remember

3. Please indicate the academic year you started at Georgia Tech.

- 2018-2019
- 2017-2018
- 2016-2017
- 2015-2016
- 2014-2015
- 2013-2014
- 2012-2013
- 2011-2012
- Before 2011

Q32 Have you ever had a full or part time job?

- Yes
- No

Q33 Have you ever had an internship or co-op? Select all that apply.

- Yes, I have had an internship
- Yes, I have had a co-op
- No, I have never had an internship or a co-op

Q44 For what purposes did you create sketches **by hand** during for your Capstone Project this semester? (Select all that apply)

- ☐ Free-body diagrams
- ☐ Idea Generation
- ☐ Communication with teammates
- ☐ Communication with TAs/Instructors
- ☐ Diagrams to assist with building prototypes
- ☐ Other (please specify) ________________
- ☐ ⊗ I did not create any sketches

Q46 How frequently did you create sketches **by hand** for your Capstone classwork this semester?

- ○ Never
- ○ 1-5 times throughout the semester
- ○ 6-15 times throughout the semester
- ○ 1-2 per week
- ○ 2+ times per week

Q34 In regards to building prototypes for your Capstone Project, how often do you draw a sketch **by hand** before making a new prototype?

- ◯ Before every adjustment or redesign
- ◯ Before major adjustments or redesigns
- ◯ Only when creating a completely new prototype
- ◯ Only for the initial brain-storming process (before building a physical prototype)
- ◯ I have never created a hand-drawn sketch of my prototype
- ◯ I did not build a prototype for any class project this semester

---

Q38 Think back to when you were deciding where to attend college. What, if any, facilities or spaces positively impacted your decision to enroll at Georgia Tech? (List all that apply, separated by commas.)

____

____

____

____

____

For the next section of the survey we are investigating your involvement in university maker spaces. A university maker space is a location associated with your university, designed to give prototyping access to students. Maker spaces give students access to prototyping equipment such as 3D printers and CNC machines for personal and/or class projects.

Examples of university maker spaces at Georgia Tech include the Invention Studio and the BME Machine Shop.

---

4. Select the statement that best describes your familiarity with university maker spaces.

○ I have never heard of any university maker spaces.

○ I have heard of university maker spaces but I have never used any of the equipment and/or resources.

○ I have used a university maker space's equipment and/or resources.

Skip To: 20. If Select the statement that best describes your familiarity with university maker spaces. = I have never heard of any university maker spaces.

Skip To: 20. If Select the statement that best describes your familiarity with university maker spaces. = I have heard of university maker spaces but I have never used any of the equipment and/or resources.

---

5. Which university maker space have you used before?
Select all that apply.

☐ Invention Studio

☐ BME Machine Studio

☐ The Hive (ECE Maker Space)

☐ Aero Maker Space

☐ Other (please specify): ____

---

6. Are you or have you ever been a student volunteer or employee of a university maker space?

○ No, I have never been a student volunteer or employee of a university maker space

○ No, but I am interested in becoming one

○ Yes, **I was** a student volunteer or employee of a university maker space in a previous semester

○ Yes, **I am currently** a student volunteer or employee of a university maker space

7. Please indicate the number of semesters you have been a student volunteer or employee of a university maker space (if you have never been a student volunteer or employee, put 0)

____

8. Select all the university maker spaces for which you are or have been a student volunteer or employee.

☐ Not Applicable

☐ Invention Studio

☐ BME Machine Shop

☐ Other (please specify) :

____

9. Have you ever used a university maker space to work on any of the following types of projects?
Select all that apply.

- ☐ Class projects
- ☐ Personal projects
- ☐ Research projects
- ☐ Entrepreneurial projects
- ☐ Club or organization projects
- ☐ Other (please specify) : ____

10. During **this semester** (Fall 2019), have you used a university maker space to work on any of the following types of projects?
Select all that apply.

- ☐ Class projects
- ☐ Personal projects
- ☐ Research projects
- ☐ Entrepreneurial projects
- ☐ Club or organization projects (Student Competition Center, SAE, etc.)
- ☐ Other (please specify) : ____

Display This Question:

If During this semester (Fall 2019), have you used a university maker space to work on any of the fo... = Club or organization projects (Student Competition Center, SAE, etc.)

Q47 What organization(s) have you worked on projects for using maker space equipment? (Please list, separated by commas).

____

11.
Select all the classes for which you have ever used a university maker space's equipment and/or resources.
Select all that apply.

- ☐ ME 1770
- ☐ ME 2110
- ☐ ME 4182 (Capstone)
- ☐ BME 2310
- ☐ BME Capstone
- ☐ Other (list) : ____

12.
During **this semester** (Fall 2019), for which of the following classes are you actively

using a university maker space's equipment and/or resources.
Select all that apply.

- ☐ ME 1770
- ☐ ME 2110
- ☐ ME 4182 (Capstone)
- ☐ BME 2310
- ☐ BME Capstone
- ☐ Other (please specify) : ______________________________

13. Have you ever participated in any of the following activities utilizing a university maker space?
Select all that apply.

- [ ] Designing something
- [ ] Building something
- [ ] Fixing something
- [ ] Collaborating with other students in a project
- [ ] Helping students with their projects
- [ ] Teaching other students how to use some piece of equipment
- [ ] Advising students on how to approach a design problem
- [ ] Learning how to use a piece of equipment
- [ ] Participating in Invention Studio or similar university maker space related events (e.g. Ladies Night)
- [ ] Attending training session
- [ ] Other (please specify) :

____

14. How much time have you spent **this semester** (Fall 2019), during a typical week, in university maker space related activities?

- None
- Less than 1 hour
- 1-2 hours
- 3-5 hours
- 6-10 hours
- 11-20 hours
- Over 20 hours

15.
In comparison to **previous semesters,** how would you rank the amount of time you have spent during a typical week **this semester** (Fall 2019) in a university maker space?

- I spent less time than previous semesters
- I spent as much time as previous semesters
- I spent more time than previous semesters
- This is my first semester being involved

---

16. Please estimate the frequency in which you have been involved in university maker space related activities **this semester** (Fall 2019)?

- ◯ Did not participate in any of the activities this past semester
- ◯ Daily
- ◯ 2-3 times a week
- ◯ Once a week
- ◯ 2-3 times a month
- ◯ Once a month
- ◯ Less than once a month
- ◯ Once a semester

17. In comparison to **previous semesters,** how would your involvement in a university maker space during **this semester** (Fall 2019)?

- ◯ I was less involved than previous semesters
- ◯ I was as involved previous semesters
- ◯ I was more involved than previous semesters
- ◯ This is my first semester being involved

18. Please estimate the number of different projects (personal, classroom, research, club or organizational related, entrepreneurship) that you have worked on using any of a university maker space's equipment and collaboration areas during **this semester** (Fall 2019) ?

____

19. In comparison to previous semesters, how would you rank the number of projects you have worked on during a typical week this semester in a university makerspace?

- ◯ I have worked on fewer projects
- ◯ I have worked on about the same number of projects
- ◯ I have worked on more projects
- ◯ This is my first semester being involved

Q39 Prior to coming to Georgia Tech, did you take a tour of a maker space (i.e. the Invention Studio)?

- ◯ Yes
- ◯ No, but I was aware of maker space(s) on campus
- ◯ No
- ◯ Not sure/do not recall

Display This Question:

If Prior to coming to Georgia Tech, did you take a tour of a maker space (i.e. the Invention Studio)? = Yes

Or Prior to coming to Georgia Tech, did you take a tour of a maker space (i.e. the Invention Studio)? = No, but I was aware of maker space(s) on campus

Q40 How did the campus maker spaces influence your decision to enroll at Georgia Tech?

- ◯ Extremely positively
- ◯ Somewhat positively
- ◯ Neither positively nor negatively
- ◯ Somewhat negatively
- ◯ Extremely negatively

Q43
Several companies have begun to build maker spaces at their offices or manufacturing sites for their employees and families to use free of charge.How does a company having a maker space impact your interest in working for that company?

- ◯ Extremely positively
- ◯ Somewhat positively
- ◯ Neither positively nor negatively
- ◯ Somewhat negatively
- ◯ Extremely negatively

20. **Directions: Please answer all of the following questions fully by selecting the answer that best represents your beliefs and judgement of your current abilities. Answer each question in terms of who you are and what you know today about the given tasks.**

Rate your degree of CONFIDENCE (i.e. belief in your current ability) to perform the

following tasks by recording a number from 0 to 100.
(0 - cannot do at all; 50 = moderately can do; 100 = highly certain can do)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
identify a design need	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
research a design need	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
develop design solutions	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
select the best possible design	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
construct a prototype	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
evaluate and test a design	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
communicate a design	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
redesign	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

21
Rate how MOTIVATED you would be to perform the following tasks by recording a

number from 0 to 100.
(0 - not motivated; 50 = moderately motivated; 100 = highly motivated)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design											
identify a design need											
research a design need											
develop design solutions											
select the best possible design											
construct a prototype											
evaluate and test a design											
communicate a design											
redesign											

22

Rate how SUCCESSFUL you would be in perform the following tasks by recording a number from 0 to 100.
(0 - cannot expect success at all; 50 = moderately expect success; 100 = highly certain of success)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design											
identify a design need											
research a design need											
develop design solutions											
select the best possible design											
construct a prototype											
evaluate and test a design											
communicate a design											
redesign											

23

Rate your degree of ANXIETY (how apprehensive you would be) in perform the following

tasks by recording a number from 0 to 100.
(0 - not anxious at all; 50 = moderately anxious; 100 = highly anxious)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
identify a design need	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
research a design need	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
develop design solutions	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
select the best possible design	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
construct a prototype	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
evaluate and test a design	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
communicate a design	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
redesign	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

24. What is your gender?

- ○ Please specify: ____
- ○ Prefer not to disclose

25. What is your race/ethnicity?
Select all that apply.

- ☐ White/Caucasian
- ☐ Black or African American
- ☐ American Indian or Alaskan Native
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ Middle Eastern
- ☐ Asian
- ☐ Prefer not to disclose
- ☐ Other ____

26. Do you consider yourself to be of Hispanic, Latino, or of Spanish origin?

- ○ Yes, Hispanic, Latino, or of Spanish origin
- ○ No, not Hispanic, Latino, or of Spanish origin
- ○ Prefer not to disclose

27. What is the highest level of education completed by either one of your parents or guardians?

- ◯ Did not complete high school
- ◯ High school/GED
- ◯ Some college
- ◯ Bachelor's degree
- ◯ Master's degree
- ◯ Advanced graduate work or Ph.D.
- ◯ Not Sure

Q49 What organizations on campus are you a member/involved in? (i.e. Student Competition Center, RoboJackets, Honor Societies, etc.) (Please list, separated by a comma).

____

28. Any additional comments:

____

Thank you for your time!

End of Block: Maker Survey

Start of Block: Block 1

Q37 Thank you for completing this survey! This data is extremely valuable to our research on the impact of maker spaces on Georgia Tech students.
You will be contacted within the week with instructions on how and when to obtain your $20 compensation.
If you have any questions, please contact Timothy Sawchuk at tsawchuk3@gatech.edu.

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